the same portion which illuminated the clouds directly overhead at the time of observation. The rainbow suffered no diminution of brightness where it was apparently crossed by the fluted shadows, the latter being far away in comparison with the bow-producing raindrops, which, of course, were in sunshine.

I regret that I am unable to send a photograph or sketch of the phenomenon, which was a most beautiful one, and must be of rare occurrence. I have never before seen anything similar, nor have I read anywhere a description of a rainbow after sunset.

Allahabad, India, September 18. S. A. HILL.

Occurrence of *Sterna anglica* in Belfast Lough.

IT may possibly interest some of your ornithological readers to know that towards the end of September a specimen of the gull-billed tern (*Sterna anglica*) was shot in Belfast Lough. The bird was placed in the hands of Mr. Darragh, of the Museum of that town, and brought by him to me for determination. On consulting the last edition of "Yarrell," I find that it does not appear to have been previously recorded from Ireland.

ROBERT O. CUNNINGHAM.

Queen's College, Belfast, October 8.

MODERN VIEWS OF ELECTRICITY.[1]

PART II.

III.

WE have now glanced through electro-static phenomena, and seen that they could be all comprehended and partially explained by supposing electricity to be a fluid of perfect incompressibility—in other words, a liquid—permeating everywhere and everything; and by further supposing that in conducting matter this liquid was capable of free locomotion, but that in insulators and general space it was as it were entangled in some elastic medium or jelly, to strains in which electrostatic actions are due. This medium might be burst, in a disruptive discharge, but easy flow could go on only through channels or holes in it, which therefore were taken to represent conductors; and it was obvious that all flow must take place in closed circuits.

To-day I want to consider the circumstances of this flow more particularly: to study, in fact, the second division of our subject (see classification on page 532), viz. *Electricity in locomotion.*

I use the term "locomotion" in order to eliminate rotation and vibration: it is translation only with which we intend now to concern ourselves.

Consider the modes in which *water* may be made to move from place to place; there are only two: it may be pumped along pipes, or it may be carried about in jugs. In other words, it may travel *through* matter, or it may travel *with* matter. Just so it is with *heat* also: heat can travel in two ways: it can flow *through* matter, by what is called "conduction," and it can travel *with* matter, by what is called "convection." There is no other mode of conveyance of heat. You frequently find it stated that there is a third method, viz. "radiation"; but this is not truly a conveyance of *heat* at all. Heat generates radiation at one place, and radiation reproduces heat at another; but it is radiation which travels, and not heat. Heat only naturally flows from hot bodies to cold, just as water only naturally flows down hill; but radiation spreads in all directions, without the least attention to where it is going. Heat can only flow one way at any given point, but radiation travels all ways at once. If water were dissociated on one planet into its constituent gases, and if these recombined on another planet, it would not be water which travelled from one to the other, neither would the substance obey the laws of motion of water—water would be destroyed in one place, and reproduced in another; just so is it with the relation between radiation and heat.

Heat, then, like water, has but two direct modes of conveyance from place to place. For *electricity* the same is true. Electricity can travel with matter, or it can travel through matter; by convection or by conduction, but in no other known way.

Conduction in Metals.

Consider, first, conduction. Connect the poles of a voltaic battery to the two ends of a copper wire, and think of what we call "the current." It is a true flow of electricity among the molecules of the wire. If electricity were a fluid, then it would be a transport of that fluid; if electricity is nothing material, then a current is no material transfer; but it is certainly a transfer of electricity, whatever electricity may be. Permitting ourselves again the analogy of a liquid, we can picture it flowing through, or among, the molecules of the metal. Does it flow through or between them? Or does it get handed on from one to the next continually? We do not quite know; but the last supposition is often believed to most nearly represent the probable truth. The flow may be thought of as a perpetual attempt to set up a strain like that in a dielectric, combined with an equally perpetual breaking down of every trace of that strain. If the atoms be conceived as little conductors vibrating about and knocking each other, so as to be easily and completely able to pass on any electric charge they may possess, then, through a medium so constituted, electric conduction could go on much as it does go on in a metal. Each atom would receive a charge from those behind it, and hand it on to those in front of it, and thus may electricity get conveyed along the wire. Do not, however, accept this picture as anything better than a *possible* mode of reducing conduction to a kind of electrostatics—an interchange of electric charges among a series of conductors. If such a series of vibrating and colliding particles existed, then certainly a charge given to any point would rapidly distribute itself over the whole, and the potential would quickly become uniform; but it by no means follows that the actual process of conduction is anything like this. Certainly it is not the simplest mode of picturing it for ordinary purposes. The easiest and crudest idea is to liken a wire conveying electricity to a pipe full of marbles or sand conveying water; and for many purposes, though not for all, this crude idea suffices.

Leaving the actual mode of conveyance as unknown, let us review how much is certainly known of the process called conduction.

This much is certainly known:—

(1) That the wire gets heated by the passage of a current.

(2) That no trace of a tendency to reverse discharge or spring back exists.

(3) That the electricity meets with a certain amount of resistance or friction-like obstruction.

(4) That this force of obstruction is accurately proportional to the speed with which the electricity travels through the metal—that is, to the intensity of the current per unit area.

About this last fact a word or two must be said. The amount of electricity conveyed per second across a unit area is called the intensity of current; and experiment proves, what Ohm originally guessed as probable from the analogy of heat conduction, that this intensity is accurately proportional to the slope of potential which causes the flow; or, in other words (since action and reaction are equal and opposite), that a current in a conductor meets with an obstructive electromotive force exactly proportional to itself. The particular ratio between the two depends upon the particular material of which the conductor is composed, and is one of the constants of the material, to be determined by direct measurement. It is called its "specific conductivity" or its "specific resistance" according to the way it is regarded. The law here stated is called Ohm's law, and is one of the most accurately-known laws there are. Nevertheless it is an empirical relation; in other words, it has not yet been accounted for—it must be accepted as an experimental fact. Undoubtedly, it is one of vast and far-reaching importance: it asserts a connexion between electricity and ordinary matter of a definite and simple kind.

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[1] Continued from p. 561.

Now if we think of this opposing electromotive force as analogous to friction, it is very easy to think of heat being generated by the passage of a current, and to suppose that the rate of heat-production will be directly proportional to the opposing force and to the current driven against it—as in fact Joule experimentally proved it to be.

But if we are not satisfied with this vague analogy, and wish to penetrate into the ultimate nature of heat and the mode in which it can be generated, then we can return to the consideration of a multitude of oscillating and colliding particles moving with a certain average energy which determines what we call the temperature of the body. If now one or more of these bodies receives a knock, the energy of the blow is speedily shared among all the others, and they all begin to move rather more energetically than before: the body which the assemblage of particles constitutes is said to have risen in temperature. This illustrates the production of heat by a blow or other mechanical means. But now, instead of *striking* one of the balls, give it an electric charge; or, better still, put within its reach a constant reservoir of electricity from which it can receive a charge every time it strikes it, and at the same time put within the reach of some other of the assemblage of particles another reservoir of infinite capacity which shall be able to drain away all the electricity it may receive. In practice there is no need of infinite reservoirs: all that is wanted is to connect two finite reservoirs, or "electrodes," as one might now call them, with some constant means of propelling electricity from one to the other, *i.e.* with the poles of a voltaic battery or a Holtz machine.

What will be the result of thus passing a series of electric charges through the assemblage of particles? Plainly the act of receiving a charge and passing it on will tend to increase the original motion of each particle; it will tend to raise the temperature of the body. In this way, therefore, it is possible to picture the mode in which an electric current generates heat.

But although this process may be used as a possible analogy, it cannot be a true and complete statement of what occurs; for it is essentially the mode of propagation of *sound*. Sound travels at a definite and known velocity, being a mechanical disturbance handed on from particle to particle in the manner described. But heat, being some mode of motion, must also be handed on after some analogous fashion, so that when heat is supplied to one point of a mass it spreads or diffuses through it. It is difficult to suppose the conduction of heat to be other than the handing on of molecular quiverings from one to another, and yet it takes place according to laws altogether different from those of the propagation of the gross disturbance called sound. The exact mode of conduction of heat is unknown, but, whatever it is, it can hardly be doubted that the conduction of electricity through metals is not very unlike it, for the two processes obey the same laws of propagation: they are both of the nature of a diffusion, they both obey Ohm's law, and a metal which conducts heat well conducts electricity well also.

Conduction in Liquids.

Leaving the obscure subject of conduction in metals for the present, let us pass to the consideration of the way in which electricity flows through liquids. By "liquids," in the present connexion, one more particularly means definite chemical compounds, such as acids, alkalies, salt and water, and saline solutions generally. Some liquids there are, like alcohol, turpentine, bisulphide of carbon, and possibly water, which, when quite pure either wholly or very nearly decline to conduct electricity at all. Such liquids as these may be classed along with air and gases as more or less perfect dielectrics. Other liquids there are, like mercury and molten metals generally, which conduct after precisely the same fashion as they do when solid. These therefore are properly classed among metallic conductors.

But most chemical compounds, when liquefied either by heat or by solution, conduct in a way peculiarly their own; and these are called "electrolytes."

The present state of our knowledge enables us to make the following assertions with considerable confidence of their truth:—

(1) Electrolytic conduction is invariably accompanied by chemical decomposition, and in fact only occurs by means of it.

(2) The electricity does not flow *through*, but *with*, the atoms of matter, which travel along and convey their charges something after the manner of pith balls.

(3) The electric charge belonging to each atom of matter is a simple multiple of a definite quantity of electricity, which quantity is an absolute constant quite independent of the nature of the particular substance to which the atoms belong.

(4) Positive electricity is conveyed through a liquid by something equivalent to a procession of the electropositive atoms of the compound in the direction called the direction of the current; and at the same time negative electricity is conveyed in the opposite direction by a similar procession of the electro-negative atoms.

(5) On any atom reaching an electrode it may be forced to get rid of its electric charge, and, combining with others of the same kind, escape in the free state: in which case visible decomposition results. Or it may find something else handy with which to combine—say on the electrode or in the solution; and in that case the decomposition, though real, is masked, and not apparent.

(6) But, on the other hand, the atom may cling to its electric charge with such tenacity as to stop the current: the opposition force exerted by these atoms upon the current being called polarization.

(7) No such opposition force, or tending to spring back, is experienced in the interior of a mass of fluid: it occurs only at the electrodes.

It would take too long to go into the evidence for these statements and to adduce examples: I will try and make the process of electrolytic conduction clearer by reverting to our mechanical analogies and models.

Looking back to Figs. 5 and 6 (p. 559), we see illustrations of metallic conduction and of dielectric induction. In each case an applied electromotive force causes some movement of electricity; but, whereas in the first case it is a continuous almost unresisted movement or steady flow through or among the atoms of matter, in the second case it is a momentary shift or displacement only, carrying the atoms of matter with it, and highly resisted in consequence:—resisted, not with a mere frictional rub which retards but does not check the motion, but by an active spring back force, which immediately checks all further current, produces what we call "insulation," and ultimately, when the propelling force is removed, causes a quick reverse motion or discharge. But the model is plainly an incomplete one: for what is it that the atoms are clinging to? What is it ought to take the place of the *beam* in the crude mechanical contrivance? Obviously another set of atoms, which are either kept still or urged in the opposite direction by a simultaneous opposite displacement of negative electricity. We are to picture two or any number of rows of beads, each row threaded on its appropriate cord; the cords alternately representing positive and negative electricity respectively, and being simultaneously displaced in opposite directions by any applied E.M.F. The beads threaded on any one cord have, in a dielectric, elastic attachments to those on some opposite cord, and thus continuous motion of the cords in opposite directions is prevented: only a slight displacement is permitted, followed by a spring back and oscillation after the fashion already described.

Very well; now picture the elastic connexions between the beads all dissolved, and once more apply a force to each cord, moving half of them one way and the alternate half the other way, and you have a model illustrating an electrolyte and electrolytic conduction. The atoms are no longer attached to each other, but they are attached to the cord. In the first respect, an electrolyte differs from a dielectric; in the second, it differs from a metal.

Moreover, electrolytic conduction is perceived to be scarcely of the nature of true conduction: the electricity does not slip through or among the molecules, it goes with them. The constituents of each molecule are free of each other, and while one set of atoms conveys positive electricity, the other set carries negative electricity in the opposite direction; and so it is by a procession of free atoms that the current is transmitted. The process is of the nature of convection: the atoms act as carriers. Free locomotion of charged atoms is essential to electrolysis.

In order to compare with Figs. 5 and 6, so as to bring out the points of difference, Fig. 13 is drawn. The beads representing one set of atoms of matter are tightly attached to the cord, no trace of slip between them being permitted, but otherwise they are free, and so are represented as supported merely by rings sliding freely on glass rods. The only resistance to the motion, beside the slight friction, is offered at the electrode, which is typified by the spring-backed knife-edge, Z. This is supposed to be able to release the beads from the cord when they are pressed against it with sufficient force. The cling between the bead and cord (*i.e.* between each atom and its charge) is great enough to cause a perceptible compression of the springs, and accordingly to bring out a recoil force in imitation of polarization.

The piece of cord accompanying each bead on its journey (*i.e.* the length between it and the next bead) represents the atomic charge, and is a perfectly constant quantity: the only variation permissible in it is that some kinds of atoms have twice as much, or are twice as far apart on their cord, and these are called by chemists dyad atoms; another kind has three times as much, another four, and so on; these being called triad, tetrad, &c.

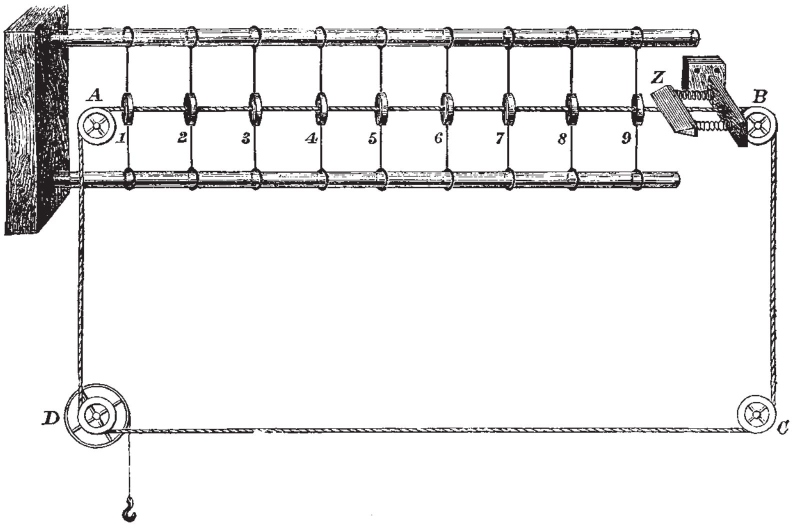

FIG. 13.—Crude mechanical analogy, illustrating a few points in a circuit partly *electrolytic*.

If the cord be taken to represent positive electricity, the beads on it may represent atoms of hydrogen, or other monad *cation*, travelling down stream to the cathode. Another cord representing negative electricity may be ranged alongside it, with its beads twice as far apart, to represent the atoms of a dyad *anion*, like oxygen. If the cords are so mechanically connected that they must move with equal pace in opposite directions, we have a model illustrating several important facts. The number of oxygen atoms liberated in a given time will be obviously half the number of hydrogen atoms set free in the same time, and will therefore in the gaseous state occupy but half the volume. For any element whatever, the number of atoms liberated in any time is equal to the number of atoms of hydrogen liberated in the same time, divided by the "valency" of the element as compared with hydrogen. This law was discovered by Faraday, and appears to be precisely true; and inasmuch as the relative weight of every element is known with fair accuracy, it is easy to calculate what weight of substance any given current will deposit or set free in an hour, if we once determine it experimentally for any one substance.

We may summarize thus:—

If we apply E.M.F. to a metal we get a continuous flow, and the result is heat.

If we apply it to a dielectric we get a momentary flow or displacement, and the result is the potential energy of "charge."

If we apply it to an electrolyte we again get a continuous flow, and the result is chemical decomposition.

There are a large number of important points to which I might direct your attention in the mode by which an electric current is conveyed through liquids, but I will specially select one, viz. that it is effected by a procession of positively charged atoms travelling one way, and a corresponding procession of negatively charged atoms the other way.

Whatever we understand by a positive charge and a negative charge, it is certain that the atoms of, say a water molecule, are charged, the hydrogen positively, the oxygen negatively; and it is almost certain that they hang together by reason of the attraction between their opposite charges. It is also certain that when an electromotive force—*i.e.* any force capable of propelling electricity—is brought to bear on the liquid, the hydrogen atoms travel on the whole in one direction, viz. down hill, and the oxygen atoms travel in the other direction, viz. up hill; using the idea of level as our analogue for electric potential in this case. The atoms may be said to be driven along by their electric charges just as charged pith balls would be driven along; and they thus act as conveyers of electricity, which otherwise would be unable to move through the liquid.

Each of this pair of opposite processions goes on until it meets with some discontinuity—either some change of liquid, or some solid conductor. At a change of liquid another set of atoms continues the convection, and nothing very particular need be noticed at the junction; but at a solid conductor the stream of atoms must stop: you cannot have locomotion of the atoms of a solid. The obstruction so produced may stop the procession, and therefore the current, altogether; or on the other hand the force driving the charges forward may be so great as to wrench them free, to give the charges up to the electrode which conveys it away by common conduction, and to crowd the atoms together in such a way that they are glad to combine with each other and escape.

Now notice the fact of the two opposite processions. One cannot have a procession of positive atoms through a liquid without a corresponding procession of negative ones. In other words, an electric current in a liquid necessarily consists of a flow of positive electricity in one direction, combined with a flow of negative electricity in the opposite direction. And if this is thus proved to occur in a liquid, why should it not occur everywhere? It is at least well to bear the possibility in mind.

Another case is known where an electric current certainly consists of two opposite streams of electricity, viz. the case of the Holtz machine. While the machine is being turned, with its terminals somehow connected, the glass plate acts as a carrier conveying a charge from one collecting comb to the other at every half revolution; but, whereas it carries positive electricity for one half a rotation, it carries negative for the other half. The top of the Holtz disk is always, say, positively charged, and is travelling forward, while the bottom half, which is travelling backward at an equal rate, is negatively charged.

In the Holtz case the speeds are necessarily equal, but the charges are not. In the electrolytic case the charges are necessarily equal, but the speeds are not. Each atom has its own rate of motion in a given liquid, independently of what it may happen to have been combined with. This is a law discovered by Kohlrausch. Hydrogen travels faster than any other kind of atom; and on the sum of the speeds of the two opposite atoms in a compound the conductivity of the liquid depends. Acids therefore in general conduct better than their salts.

OLIVER J. LODGE.

(*To be continued.*)

JOSEPH BAXENDELL, F.R.S.

We have already announced the death of Joseph Baxendell, an event which took place on Friday, the 7th inst., at the Observatory, Southport.

Born at Manchester in 1815, he had not the advantage of a thorough scientific training, such an education being much less frequent at that early period than it is at the present day. On the contrary, he had to make his way in the world, and went to sea when quite a youth. We are all of us moulded by circumstances, and while Baxendell no doubt inherited an aptitude for science, yet the particular bent which this took was unquestionably determined by the circumstances of his profession. An intelligent seaman cannot fail to be impressed with the importance of astronomy and meteorology, and it was in these two sciences that Baxendell especially distinguished himself in after life.

Meanwhile, notwithstanding the engrossing duties of a sailor, his energy and perseverance in the pursuit of science were such that he was enabled to supplement the deficiencies of his limited education, acquiring a knowledge of mathematics which was of great service to him in his investigations. A training of this kind is well qualified to produce a mature and thoughtful student of Nature, and it had this effect upon Baxendell. Owing to a retiring disposition, he was not much seen in general scientific society, but was, on the other hand, very highly esteemed by students like himself. A gathering of such students usually takes place once a fortnight during the winter months at the rooms of the Manchester Literary and Philosophical Society. At these meetings Baxendell was a most regular attendant, and he ultimately became Secretary of the Society as well as editor of its publications. It is in the Memoirs and Proceedings of this Society that most of his scientific contributions will be found, and in astronomy it is only necessary to notice his catalogue of variable stars, which is very highly esteemed by all observers.

Baxendell's contributions to meteorology are very important, and in one branch of this science he may claim to be the pioneer. In 1871, from an analysis of eleven years' observations of the Radcliffe Observatory, Oxford, he came to the conclusion that the forces which produce the movements of the atmosphere are more energetic in years of maximum than in years of minimum sun-spot activity. This conclusion has now been confirmed in various directions by other observers. We have heard it objected that Baxendell generalized from a comparatively small number of observations, but in a question like this such a procedure is essential to the pioneer. His task is to deduce with a mixture of boldness and prudence something of human interest out of the mass of observations already accumulated, and thus to stimulate meteorologists not only to go on with their labour, but to cover more ground in the future than they have covered in the past. Baxendell's procedure in this respect has been abundantly justified by the fact that many other men of science are now following in his footsteps.

It is believed that he was the first to propose the use of storm-signals which are now universally adopted by all maritime nations. He likewise foretold the long drought of 1868, and enabled Manchester to take precautionary measures which had the effect of rendering the inconvenience less severe. As an astronomer and meteorologist Baxendell was naturally interested in a study of the sun, and was an independent discoverer of the fact that the faculæ which accompany sun-spots are for the most part thrown behind them—the word *behind* having reference to the direction of rotation of our luminary. It was, we believe, his opinion that the behaviour of sun-spots is intimately connected with that of meteoric matter around the sun. Without asserting the exact nature of the bond between these two phenomena, we think that various students of the sun's surface are now inclined to be of this opinion.

He was a Fellow of the Royal Society and of the Royal Astronomical Society. He was likewise a corresponding member of the Royal Society of Königsberg, of the Scientific and Literary Academy of Palermo, and of the National Observatories of France, Germany, and Italy. For some years he enjoyed the use of his friend Mr. Robert Worthington's observatory at Crumpsall. On the death of the Rev. H. H. Jones, in 1859, he was appointed Astronomer to the Manchester Corporation. Latterly his health forced him to reside at Southport, in the neighbourhood of which he continued his observations until his death.

BALFOUR STEWART.